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Opportunities and Challenges for Incorporating Case Studies from Developing Countries in Core Engineering Courses

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Abstract: *Engineering education must adapt to the emerging approaches put forward by international development actors. In a globalised world, the work of future engineers will be carried out in many contexts. In the case of developing countries, the Technology for Human Development (THD) approach is increasingly being integrated in the practice of engineering. On the other hand, in industrialised countries, the lessons learned from development projects may contribute to a more sustainable engineering practice.*

The purpose of this paper is to show the use of case studies from developing countries as a valuable method for teaching engineering with a human and sustainable development perspective. It will illustrate case studies from the Education for Development (ED) programme of Engineering Without Borders Spain (ISF-Spain). Some of them have been successfully implemented in core and elective courses of the Technical University of Catalonia. These experiences highlight the feasibility and the acquiescence of many teachers for incorporating case studies based on THD into engineering courses. In contrast, some challenges arise in the dissemination of this methodology, especially in core courses.

INTRODUCTION

While the concept of Sustainable Development is becoming deeply embedded in the practice of engineering, new needs emerge as a result of an interconnected world. Nowadays, international development engineering actions must also integrate the concept of Technology for Human Development (THD). Indeed, as Pérez-Foguet and Saz-Carranza (2004) assert, incorporating a THD approach when working in less developed areas is complementary to the Sustainable Development approach and is increasingly demanded by international organisations and NGOs.

Engineers Without Borders Spain (ISF-Spain) is a development NGO that has promoted many Education for Development (EC) academic activities in Spanish technical universities (see Perez-Foguet et al. 2004 for further information). The action presented in this paper has been based on field experiences from ISF-Spain projects. Most of these works have been carried out in partnership with universities from the South. This shared learning provides useful tools for developing new educational materials based on a case study approach.

This paper will first discuss the use of technology in developing countries and the current trends in the engineering sector that are promoted by international organisations and NGOs. It will then analyse the use of case studies from developing countries in practice-oriented fields of higher education such as engineering, architecture and planning. In section three, the case studies prepared by ISF-Spain are presented. A brief description of each case is given, paying special attention to those which have been actually incorporated in core engineering courses. The last section will review the main difficulties found integrating these examples into engineering courses, but also the interest shown by some teachers who wish to offer courses that are more comprehensive.

RETHINKING TECHNOLOGY IN LESS DEVELOPED REGIONS

The case studies presented in this paper are based on a THD approach. This concept considers technology in such a manner as to achieve human development in all its dimensions (Perez-Foguet et al. 2004). The following is an example to show the significance of THD as a complementary approach to Sustainable Development.

Sanitation is one of the fields of engineering that has evolved the most during recent years. As the fourth and latest edition of the famous Metcalf & Eddy wastewater manual (Tchobanoglous, 2003) reveals, the latest technological and biotech advances have been adopted by wastewater engineering in order to respect environmental requirements imposed by governments of industrialised countries. Nonetheless, these valuable improvements towards more sustainable management of water resources are not very useful in the case of developing countries (Oliete-Josa, 2004). While in the developed world the efforts have been primarily devoted to improving treatment and reuse of reclaimed water, in less developed countries priorities are still sewage evacuation and disposal, particularly in urban areas. Unfortunately, wastewater engineering manuals and university textbooks are progressively moving away from low-cost and basic technology.

This example illustrates that the will for improving technology under a sustainable development perspective does not necessary imply development for the poor. In addition, two essential features of THD arise. First, the THD approach must seek an evolution in the engineering profession in order to improve its capacity to act in contexts with different levels of development. Second, THD implies a change in research priorities to allow technological innovations to actually promote human development. According to the United Nations Development Programme, "technological innovations advance human development by increasing productivity that raises household incomes and by providing solutions to problems of disease, transport, energy, water supply, sanitation and information and communications technology for education" (UNDP, 2003).

Another characteristic of THD is the affordability of the technology. Today, most

technology is designed with high levels of sophistication based on Northern standards, resulting in low-income families being unable to pay the price of the goods and services produced. As the 2003 Human Development Report claims, technology is affordable for poor people when designs suit different income levels (UNDP, 2003). This report introduces the Millennium Development Goals (MDG), which have been set out in 2000 at "The Millennium Assembly of The United Nations". The goals represent the commitment of constituent states to sustainable development and the eradication of poverty. They are a series of milestones and challenges that are to be met by 2015.

Including a social and political reasoning in engineering practice and education is one of the most important challenges of THD. What is more, it is becoming increasingly imperative for international development strategies. In its recent World Development Report on services for the poor, the World Bank asserts that "lack of knowledge about the right technical solution is probably not the binding constraint. What is needed is a set of institutional arrangements that will give policymakers, providers, and citizens the incentives to adopt the solution and adapt it to local conditions" (World Bank, 2004)., Nowadays however, many engineers do not have an education that allows them to manage problems with a comprehensive approach much beyond the technical and economic aspects.

Significant studies propose combining social, political and technical sciences in order to build a more comprehensive engineering field. For example, Forester (1987, 1989, 1999), currently one of the most prominent planning theorists, argues that planners must think politically as well as technically. According to him, planning is not only a technical practice, but also an effort to build consensus towards commonly perceived goals, emphasizing democracy and participation. Prados (1997), former editor of the ASEE Journal of Engineering Education, notes that "[being an] engineer requires [an] understanding of the non-technical forces that profoundly affect engineering decisions". Tarjanne (1997), former Secretary-General of the International Telecommunication Union, warns about the digital gap between developed and developing countries and claims that Human Rights will not be achieved without universal access to basic communications and information services. Finally, Vasconcellos (2001), the Director of the National Association of Public Transport in Brazil, reviews the disappointing results of classical modelling procedures for urban transport in the case of developing countries. He suggests that these techniques are not neutral; on the contrary, "they have been used as decision tools in closed arenas" in favour of wealthy social groups.

THD in engineering education is not only addressed at students aiming to work in the international development sector. Recent publications, such as "Doing Business with the Poor" of the World Business Council for Sustainable Development (WBCSD, 2004) and "Unleashing Entrepreneurship: Making Business Work for the Poor" of the United Nations Commission on the Private Sector and Development (UNDP, 2004), underline the increasing importance of clients from developing countries for private corporations, most of them in the field of engineering.

USE OF THD CASE STUDIES IN ENGINEERING COURSES

The use of case studies in engineering education is still far from becoming as widespread as it is in business schools around the world. Nevertheless, it is a cost-effective means of bringing real-world problems into engineering courses (Raju and Sankar, 1999). As stated by Yin (1984), a case study may be defined as an empirical

inquiry that investigates a contemporary phenomenon within its real-life context. Johansson (2003) argues that in practice-oriented fields such as engineering, architecture and planning, a case study methodology may contribute to improving the capacities of professionals. According to Johansson, the ability to act in a professional framework is based on knowledge of a repertoire of cases, which are based either on personal experience or are model cases established within the profession. Nevertheless, Raju and Sankar lament the lack of case studies that bring sufficient real-life engineering challenges to the classroom. Evaluation instruments to measure the effectiveness of using case studies in engineering classrooms are also not sufficiently available.

Regarding the history of case study methodology, we can understand some of the reasons for its slow introduction into engineering education. Over the last two decades, case study methodology has merged qualitative field study methods with quantitative methods of data analysis. Additionally, as Johansson (2003) mentions, Yin (1994) has transferred experimental logic into the field of naturalistic inquiry and combined it with qualitative methods. In contrast, logical positivism and quantitative methods are still almost exclusives in engineering education. There is a resistance from many teachers to integrate qualitative approaches, which some of them still consider less scientific.

Raju and Sankar (1999) suggest a list of features that should be present in case studies that emphasise technical education. Based on the experience of cases described in next section, this list has been adapted following the THD application paths proposed by Pérez-Foguet and Saz-Carranza (2004).

Actions: operational channel

This working path is focused on intervention. Within this framework, an engineer must be able to carry out development projects and programmes as well as to define strategies and policies. Concerning this channel, engineering education must develop the procedural dimension. Therefore, in order to reinforce these capabilities, case studies need to present the following features:

- *Based on a development project or on field research* Each case study has to be self-contained so that the student has all the information needed to identify alternatives and make decisions.
- *Include technical issues* Detailed technical information relevant to the case studies has to be provided to the students. The students must understand clearly the technical issues and be able to make technical decisions.
- *Use engineering software to show the links between engineering education and real-life situations* This software should be free or affordable, as well as being capable of integrating quantitative and qualitative data.
- *Include development issues* A national and local overview of the case-study country, as well as an introduction to the environment in which each project takes place, needs to be provided.
- *Include multi-media interactive educational resources so that the connection between theory and practice is explicit* Student learning is enhanced as they analyse the written case study, read the supporting documentation, work with the provided software and consult the audio-visual materials.

Knowledge: cognitive channel

This second channel is related to knowledge generation. As mentioned above, knowledge of a broad range of cases enhances an engineer's capacity to confront new situations. In the generation of knowledge through case studies, research and teaching must not be separated, especially when talking about development issues. A research case study can be very useful in engineering education, while at the same time, discussions in the classroom can enrich engineering research. Thus, case studies must incorporate are the following features:

- *Tell a real story of a project or research that has actually been identified, planned, prepared, executed, monitored and evaluated* Case studies used in educational settings should be prepared with the same rigour as those with research purposes.
- *Bring out the human and sustainable development issues* Videos, photographs, and multi-media technologies need to be utilised so that the students can get a good understanding of the social, political, economical and technological issues involved in each case study.
- *Include an instructor's manual that is thorough and detailed* The instructor's manual needs to include a synopsis of the case, educational objectives, definition of the intended field for the case, possible format for class discussion, theoretical basis of research, and short and detailed answers to questions for class discussion. In addition, the manual must include complementary readings so that the instructor can understand the environment where the example was implemented. Frequently, the length of the instructor's manual is as much as the case study itself.
- *Test and evaluate the effectiveness of each case study in the classroom* The evaluation instruments must help the students and the instructor to develop new ideas that may improve the results of the project or research. Moreover, the instructor can send these ideas back to the people running the actual project.

Values: valorative channel

This path of THD application emphasises ethical issues of professional practice. Hence, engineering education needs to contribute to the enhancement of students' attitudes and values. Case studies are a useful tool to achieve this objective because they highlight the human dimension of real-life situations. Linked to this channel, case studies must have the following characteristics:

- *Stimulate student interest*
- *Portray the situations accurately* The case study reports the reality of what happened in an unbiased and non-judgmental manner.
- *Have a focal problem* This enables students to consider alternatives and make non-technical decisions.
- *Generate conflict among the teams* Each case has more than one viable option for the decision-makers. The students' learning experience is enhanced as they identify criteria and weigh the advantages and disadvantages of each option.
- *Have real characters to identify so that the student can role-play one of those characters*. This helps bring out the subjectivity of decisions while demonstrating how the credibility of a person influences decisions.

TEACHING THD CASE STUDIES IN THE TECHNICAL UNIVERSITY OF CATALONIA

Since 2000, ISF-Spain has been collecting the principal data of its projects in the South in order to provide case examples to be used in engineering courses. Incorporating case studies in core engineering courses is part of the objectives of the Education for Development (ED) programme and the THD outlined above. Currently, some case studies have already been used in engineering courses at the Technical University of Catalonia.

The prepared case studies cover nine topics: surveying, water supply, urban services, sanitation, rural electrification, information and communication technologies, ferrocement structures, rural water resources and urban transport. An expansion of this list is planned, using other ISF-Spain development projects. Teachers can use these materials to prepare theory classes, to arrange practical exercises and to supply supporting readings to the students. The structure of the case study materials provided to the teachers is the following:

- *A brief introduction of the case* This introduction is generally accompanied by the essential theoretical considerations needed to solve the technical issues of the case. This information is predominantly for the teachers' use.
- *Set of presentation materials* In order to reinforce the textual descriptions, the presentation package contains several audio-visual resources. There are two kinds of slides. The first is addressed to the teachers and contains a broad explanation of the case. The second is for class use and the information is summarised. In both presentations, the slide sequence is the same: it starts describing the general issue and presenting the theoretical concepts, and continues setting out a particular project where ISF-Spain has been involved. The slides finish by asking questions to generate discussion among the students.
- *A class discussion guide for teachers* This guide suggests instructor's remarks to encourage students to participate. In addition, it includes prepared answers to frequently asked questions. Finally, it proposes some alternatives, such as creating opposed discussion groups or organising role-plays.
- *Two practical exercises* Using real data, exercises aim to show how engineering, and particularly engineering software, can be applied to development projects. The first exercise is solved and arranged to be explained in the classroom. It also includes some practical suggestions for teachers. The second exercise is proposed to be solved by the students at home. To resolve both exercises, specialised software is needed. Usually, each case study uses different software. Criteria for software choice are: 1) Appropriate technical specialisation, 2) Free access or affordability, 3) Learning time needed to run it and 4) Capability to integrate quantitative and qualitative data. Where necessary, the software manuals are also supplied.
- *Supporting readings and on-line references* Most slides contain notes with recommended readings. Some documents are provided and others are available on the web. Additionally, bibliographic references are supplied.

Until now, these case study resources have been only developed in electronic format. In previous experiences, a CD-ROM has been provided to the teachers. Presently, paper materials are also being prepared. The objective is to put these case studies and relevant complementary material in the form of a textbook to be published. Furthermore,

materials distributed to the students are being improved and enlarged.

The case studies currently available are outlined here:

Surveying

This case study is based on a four-year land tenure legalisation programme in a rural area of El Salvador. This action started in 1999 in response to a demand made by the community-based organisations from the mountainous north of the country. Technical issues were undertaken by the Department of Structural Mechanics of the José Simeón-Cañas Central-America University (UCA) and ISF-Spain. Legal aspects were monitored by the UCA Human Rights Institute (IDHUCA).

The case study describes the work carried out by a group of volunteer engineering students, supervised by surveying teachers. This project was developed in two rural communities where the traditional plot limits had been established generations ago. Therefore, the main challenge was to identify, and sometimes negotiate, the plot limits in order to execute the surveying project.

The practical exercises provided are planimetric representations. Usually, the concepts used are already taught in classical surveying courses. For its resolution, students can use any calculation software, such as Microsoft Excel, and any graphical representation software, such as AutoCad or Microstation. By solving the exercise, students can realise the complexity and the inequities of land distribution in poor rural areas.

Water Supply

Since 1999, ISF-Spain has been undertaking a water supply program in rural areas of El Salvador. This case study describes one of their first completed projects. The project promoters were ISF-Spain and the Salvadorian NGO CORDES, who worked closely with community representatives.

Technical design was carried out by a civil engineering student who was working on his master's thesis. This work resulted in the collection of a large quantity of detailed information. In addition to general water quality and supply issues faced in Central America, the case presents considerations about the water and project cycle, community participation and technical alternatives.

Exercises are to be solved using EPANET. This software models the hydraulic and water quality behavior of water distribution piping systems. It has been developed by the Water Supply and Water Resources Division of the U.S. Environmental Protection Agency. EPANET is public domain software that can be freely copied and distributed. The student is asked to argue conclusions about supply, pressure and speed distributions in the network.

Urban Services

This case study stems from the FOURMI I programme in Cameroon, funded by the European Union. The Upgrading Program in Yaounde 6 seeks the empowerment of slum populations by means of infrastructure micro-projects. Capacity building is attained thanks to a high degree of community participation in all stages of the programme. It started in 1998, with the execution of a pilot project in Melen IV. This neighbourhood had been previously undertaken as a field of study by the urban planning

researchers at the Technical School of Yaoundé. ISF-Spain has been providing assistance on technical and social issues.

Slides present different micro-project investments. The goal of these micro-infrastructures is to improve urban services by enhancing accessibility inside the neighbourhoods, upgrading rain drainage networks, protecting traditional water supply points (springs and wells) to ensure a diversified supply to low-income families, and to provide improved on-site sanitation systems to protect groundwater and preserve public health.

One main problem hindering the improvement of urban services in African cities is the heterogeneous and fragmented land use. Exercises seek to characterise an urban drainage basin in order to identify different settlements and uses. Students work for this purpose with a Geographical Information System (GIS). Detailed descriptions of each kind of land use are provided so that students can recognise the different areas on the map. Presently, most GIS software on the market is quite expensive. However, some free applications such as SPRING or GRASS are available. Since exercises are not very complex, another option is to work in class with free demo versions.

Sanitation

This case study is based on a research project coordinated by the Water Sciences and Environment Laboratory of the Technical School of Yaounde. It aimed to analyse wastewater management in planned urban zones and their surroundings in Cameroonian and Chadian cities. Two ISF-Spain volunteers, both of whom were civil engineering students in the Technical University of Catalonia, did their master's theses as a part of this research project.

Physical, socio-economic and infrastructural conditions of some neighbourhoods are presented in the slides. At the same time, several sewage evacuation and treatment systems are proposed in order to discuss the best alternatives for each situation.

Similarly, exercises try to determine the best technical solution. The software used in this case is a learning application distributed with the URALITA wastewater manual for small communities. After the system has been chosen, students use the software to calculate the dimensions of the treatment plant. Sometimes, dimensions do not suit the space available. Given that space is an important issue concerning sanitation in poor urban areas, students are then obliged to start again using another system.

Rural Electrification

The information for this case was collected from energy projects in Ecuador, Peru and El Salvador; Particular attention is paid to a photovoltaic project executed in El Salvador. It was carried out by ISF-Spain in collaboration with the Department of Hydraulics and Energetic Sciences of the José Simeón-Cañas Central-America University (UCA). The goal of this project was to provide electricity to an isolated rural community of three hundred inhabitants.

Like in the other case studies, the slides begin with an overview of the difficulties found in developing countries in supplying electricity to rural areas. They continue by describing the main features of clean and sustainable energy and finish with a detailed characterisation of the system implemented in El Salvador. Students are encouraged to discuss the final solution adopted.

Technical exercises use free software developed by RETScreen Internacional, a clean

energy support centre managed under the leadership of Natural Resources Canada. The RETScreen Photovoltaic Project Model is used in this case for evaluating the energy production and life-cycle costs of an isolated-grid photovoltaic system.

Information and Communication Technologies (ICT)

This case study is based on a feasibility study for the creation of an Intranet network in Santiago del Estero, a northern province of Argentina. It also uses support information from the EHAS programme in Latin America, which aims to provide low-cost communication tools and telemedicine services to health centres in rural areas. Both programmes are backed by ISF-Spain and several Spanish, American and European organisations.

The project in Santiago del Estero plans to connect rural communities through a wireless network. Slides begin by introducing the concept of digital gap and the main difficulties in providing universal access to ICTs. Then, they present technological alternatives, as well as some projects that have already been developed. In class students discuss the alternatives, paying close attention to the technical limitations of each one.

In the exercises, students are expected to calculate the cost of a wireless network to connect remote communities; they have to take into account a possible network extension. For designing wireless antennas, WLAN Design Tools are used. This software can be downloaded free of charge.

Ferrocement Structures

Ferrocement water tanks are used in many countries for the collection and storage of water for drinking, washing, animal needs and irrigation. With this very low-cost technology, water tanks of 350 m3 and above can be built. Nevertheless, very often this technology is not taught in concrete structures courses. This case study explains the construction of one of the tanks executed by ISF-Spain in El Salvador for a water supply project.

There are not many non-technical issues to discuss with regards to ferrocement structures. Nonetheless, this case study triggers students' interest because of the problems regarding tank's location. Indeed, in addition to technical aspects, students are required to think about issues such as land ownership, difficulties with volunteer work, etc.

Exercises are solved by numerical methods. The modelling software is based on the finite element method Castem3M. This software is free when used for teaching purposes. The objective of the exercises is to model a tank with a given geometry.

Rural Water Resources

In 2001, the Salvadorian NGO CORDES and ISF-Spain agreed to develop a master plan in order to achieve a more comprehensive management of water resources in La Libertad district. This plan establishes the order for the execution of water projects. Priorities are not only determined by the lack of water resources. In addition to the urgency criterion, other features are used to classify the rural communities; these include the level of participation, the existence of previous experiences in similar projects and the economic feasibility of the project.

The class presentation starts by explaining the concept of the master plan and its

application in water resource management. It also describes the critical situation in Central America caused by a lack of water resources. Finally, the master plan of La Libertad is presented emphasizing the work done in collecting information and the principles used to prioritise the interventions. Class discussion is focused around these principles.

Exercises analyse the final order proposed by the master plan. Using a multi-criteria analysis method, students are expected to propose alternative decisions. The method used is ELECTRE III. This method is able to classify the different alternatives of a problem from the best one to the worst based on a defined set of criteria. A demo version of this software is available on the web.

Urban Transport

The last case study is based on a research project on urban transport in Cameroon. The goal of this study is to investigate the correlation between the access to transport and the human development of the inhabitants of dense informal settlements in the city centre. A civil engineering master's thesis has been done as part of this research. One important features of this case is the integration of both quantitative and qualitative data.

The teacher's presentation explains the different research methodologies used to analyse transport reality in developing cities. Starting with the classical demand simulation models, slides present new approaches based on concepts such as sustainability, democracy and equity. The presentation emphasizes the importance of non-motorised transport modes. It also highlights the links between access to transport and housing programmes for the urban poor.

Exercises are to be solved by using Qualitative Comparative Analysis (QCA). These tools may be used when there is a lack of statistical data. They are also appropriate because of their capacity to manage human development variables. By means of real data from surveys carried out in some neighbourhoods of Yaounde, students are asked to establish conclusions about human development of its inhabitants and their accessibility conditions.

CHALLENGES FOR DISSEMINATING THD CASE STUDIES

Some of the case studies presented in this paper have already been used in engineering courses of the Technical University of Catalonia. The most successful experience has been the surveying case study, which has been taught over several years in the core course of surveying and mapping of the Civil Engineering School of Barcelona. The practical surveying classes are introduced using this case study. Currently, ICT, water supply, water resources, and rural electrification cases have also been used in courses of the Civil, Telecommunications and Mechanical Schools of Barcelona. Moreover, most of these cases have been tested with ISF-Spain volunteers at informal meetings.

Teachers who have incorporated these case studies underline the importance of educating through a more comprehensive approach. Additionally, many of them think that these cases are a useful in demonstrating the real-life application of their field. Nonetheless, incorporating these case studies seems to be more feasible in elective courses; some difficulties arise with regards to core subjects. Firstly, in many engineering universities, significant differences arise between teachers when discussing

a programme's objectives, main topics and methodologies. Therefore, curricula changes are being implemented very slowly, especially in compulsory courses. Secondly, at an individual level, some teachers are reluctant to incorporate non-technical issues into their courses. They argue that they do not have sufficient class hours. Some teachers even disagree with the principle of including these topics and materials in their engineering courses.

CONCLUSIONS

In recent years, case studies have been the most used method in social and technical analysis carried out by international organisations and NGOs. This can be confirmed by taking a quick look at their reports and technical papers. For example, at the 2003 Urban Research Symposium organised by the World Bank, 32 of the 40 papers presented were case studies. This trend originated in the early nineties, when the World Bank, as well as other international organisations, started to gain awareness of the disappointing results that their policies had for the poor. Consequently, they decided to include a diversity of practices and the local institutional features into their strategies (Pincus, 2002). In addition, combining quantitative and qualitative data in development analysis is gaining recognition with development agencies (Bamberger, 2000). Engineering education programmes cannot downplay these facts. Engineers are expected to play an important role whether in the international development sector or in a transnational corporation. Technology is an important driving force that affects the life of citizens around the world. Use of case studies from development countries in core courses is a valuable method to enhance skills, knowledge and values that engineers need to meet these challenges.

These case studies are a good an example of what can be done to incorporat human and sustainable development issues into engineering education. They show that teachers are actually interested in bringing real-life cases to the classroom. Moreover, the production of these case studies is a research activity itself. Indeed, collecting the information, meeting the project managers and teachers, creating a coherent structure to be used for educational purposes, searching for the appropriate software, conceiving of and solving the exercises, etc. are a useful manner to assess and evaluate the projects and likewise to develop new educational strategies. However, this initiative is not yet fulfilled and some of the cases must still be improved and tested. In addition, there is still much work required to disseminate these case study materials. The presentation of this paper is an important step. Institutional procedures also need to be done in order to incorporate this methodology in the teaching strategies of the University. Publishing a textbook and CD-ROM may be good opportunity to circulate theses materials. In any case, a very useful way of disseminating this method is with teachers, beginning even with collaboration in the preparation of the case studies.

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